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Performance of a Coal-Fired Boiler Converted to Oil



Building Materials and Structures Report BMS111

United States Department of Commerce
National Bureau of Standards

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Performance of a Coal-Fired Boiler Converted to Oil

by Richard S. Dill and Paul R. Achenbach



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Foreword

Many coal-fired boilers are converted to the use of fuel oil each year to obtain the greater convenience of liquid fuel. Converted coal-fired boilers are usually not as efficient as boilers originally designed for fuel oil since the efficient combustion of coal requires more combustion space and larger gas passages through the boiler than does liquid fuel. The tests described in this report were made to show the advantage of using a precast lightweight combustion chamber instead of one made of standard firebrick for the oil burner and to evaluate the increase in capacity obtainable with two types of cast-iron baffles. The project was part of the research and testing program carried on at the National Bureau of Standards in cooperation with the National Housing Agency and its technical staff.

E. U. CONDON, *Director.*

Performance of a Coal-Fired Boiler Converted to Oil

by Richard S. Dill and Paul R. Achenbach

ABSTRACT

As part of the research program on heating plants for small homes being conducted at the National Bureau of Standards in collaboration with the National Housing Agency and its technical staff, the performance characteristics of cast-iron boilers, both coal- and oil-fired, have been investigated. This report discusses the performance of a cast-iron boiler designed for coal firing after it had been converted to the use of oil by means of a gun-type burner. It is shown that a refractory firebox of low heat capacity and low thermal conductivity increased the efficiency of the converted boiler several percent, and that baffles which effectively direct the hot combustion gases over the heat-transfer surface increased the capacity of the boiler up to 27 percent.

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I. Introduction

Many home owners would like to use oil fuel for heating because of the greater convenience but do not wish to discard a coal-fired boiler that is still in good condition. In general, either the gun-type or the rotary-type oil burner can be installed in a conventional coal-fired boiler or furnace to convert it to the use of oil fuel. Many boiler manufacturers offer the same boiler for use with either coal or oil, whereas others design boilers specifically for each fuel. A larger combustion chamber is usually essential for burning solid fuel to permit complete combustion of volatile gases, and larger flue-gas passages are usually provided, chiefly to allow for partial obstruction of the passages by soot and fly ash. A smaller combustion chamber and less excess air are needed for burning oil than for the combustion of coal and result in higher efficiencies than are usually obtained with a coal-fired boiler.

The original reason for the use of refractory linings in the combustion chambers of oil-burning

boilers was to protect metal parts from the action of the flames. However, it was soon observed that hot refractory material in a firebox improved combustion and increased the transfer of heat by radiation from the hot refractory to the heating surface of the boiler.

A refractory firebox made of material with low heat capacity and low conductivity will become hot more rapidly following a cold start and permit maintenance of higher temperatures during steady operation of the oil burner than one made of firebrick. This higher firebox temperature is expected to improve combustion of the fuel and increase the heat transfer by radiation to the crown sheet. Moreover, less heat will be lost by conduction through the bottom and sides of the chamber when the conductance of the refractory is low.

The combustion chamber should be large enough for the oil spray to burn in suspension, but small enough to fit the flame so that the refractory will

become hot quickly after a cold start. Turbulence in the burning gases should also be promoted to provide maximum mixing with the combustion air and stagnant pockets in corners should be avoided as far as possible.

The results of an investigation by Cross and Lyman [1]¹ with a pressure-atomizing mechanical draft burner indicated that the size of the combustion chamber affected the efficiency of a boiler considerably, but no data in relation to size were obtained in the present investigation, as the difference of 2 percent in the combustion space of the two chambers used is negligible.

Metal or refractory ceramic baffle plates are frequently installed in converted boilers to direct the hot combustion gases more effectively over the heat-transfer surface. When a gun-type oil burner is installed in the front of a boiler which has flue passages at the rear, there is a tendency for the hot gases to pass to the rear of the combustion chamber and upward to the outlet without having brushed over the front part of the crown sheet. Thus, there is, in effect, a dead air space under the forward part of the crown sheet, and this surface receives heat chiefly by radiation from below. By attaching a baffle to the rear wall of the boiler which extends halfway to the front, the hot gases are deflected forward and brought in contact with the entire crown sheet before passing up the rear flues.

Some coal-burning boilers have more than one set of uptake flues and more cross-sectional flue

area than oil-burning boilers require. If the flues nearer the front of the boiler are closed, all of the gases will be directed over the greater area of heating surface to the flue at the rear.

Economizers, which usually consist of additional water-backed heating surfaces located in the combustion space or gas passages, are also used to improve the efficiency and capacity of boilers converted to oil. They were not studied at this time as this investigation compared only the results of the use of two combustion chambers of different material and of somewhat different form. The effects of the installation of baffles and of the sealing of the clinker and firebox doors to prevent leakage were also investigated. Arthur H. Senner has reported the effect of the installation of two kinds of baffles and four kinds of economizers in round converted cast-iron boilers [2].

An investigation by Cleghorn and Helfinstine [3] shows that, of two boilers made by the same manufacturer, the boiler originally designed for oil fuel averaged 13 percent more efficient than the coal-fired boiler that had been converted to oil. The combustion chamber of the boiler designed for oil was surrounded by water-backed surfaces, which is the usual practice for some manufacturers but not for others. Baffles were not used in the conversion boiler during the comparison made by Cleghorn and Helfinstine. Therefore, the results of that comparison are not necessarily representative of all boilers of the two types.

II. Specimen and Test Equipment

The boiler used for the tests was a stock rectangular cast-iron boiler with four vertical sections enclosed in a jacket. It had 34.5 sq ft of heating surface and a grate area of 3 sq ft. There were two sets of uptake flues at the rear of the boiler, one set between the third and fourth sections, and a smaller set between the second and third sections.

The oil burner was a stock model of the pressure-atomizing, mechanical-draft type with a capacity ranging from 1 to 2 gallons of oil per hour. It had automatic intermittent ignition and the installation was equipped with the usual ignition and pressure controls.

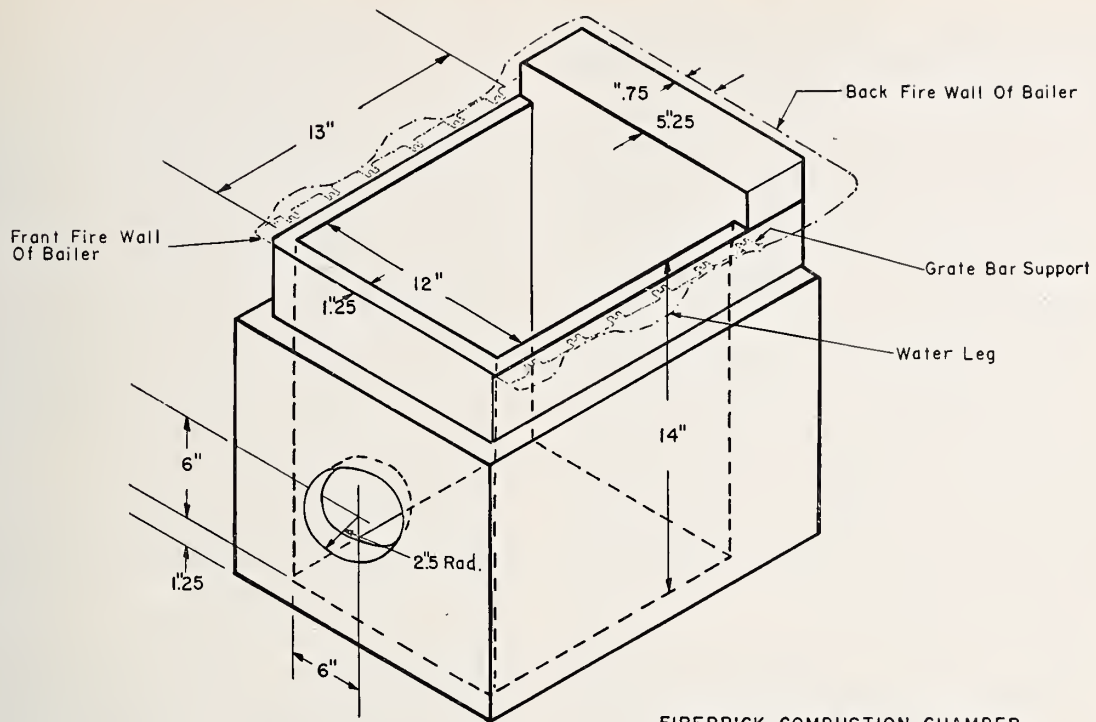
A combustion chamber of standard firebrick was first used in the boiler. This chamber was built in rectangular shape with interior dimensions 13 in. long, 12 in. wide, and 14 in. deep, in accordance with the recommendations of the oil-burner manufacturer. The space between the firebrick and the sides of the ashpit was filled with an insulating material. The chamber extended upward to a point 2 in. above the bottom of the water legs. Figure 1 shows the dimensions of

the firebrick chamber and its location in relation to the sides of the ashpit. Firebrick 2½ in. by 4½ in. by 9½ in. were used for this chamber up to the point where the grate-bar supports interfered. Split brick 1¼ in. thick were used above the grate level, thus forming the shelf at the upper edge of the chamber shown in figure 1.

The precast combustion chamber was of the type recommended by the boiler manufacturer and had a rectangular cross section in a horizontal plane. The bottom of the chamber was cylindrical in shape with the center line of the cylinder running from front to back of the boiler. The inside dimensions of the chamber were: width 12 in., length 16 in., and maximum depth 13 in. From the cylindrical bottom, the sidewalls extended vertically upward to a point 2 in. above the bottom of the water legs of the boiler. Figure 2 shows the size and shape of the precast chamber and its position in the ashpit.

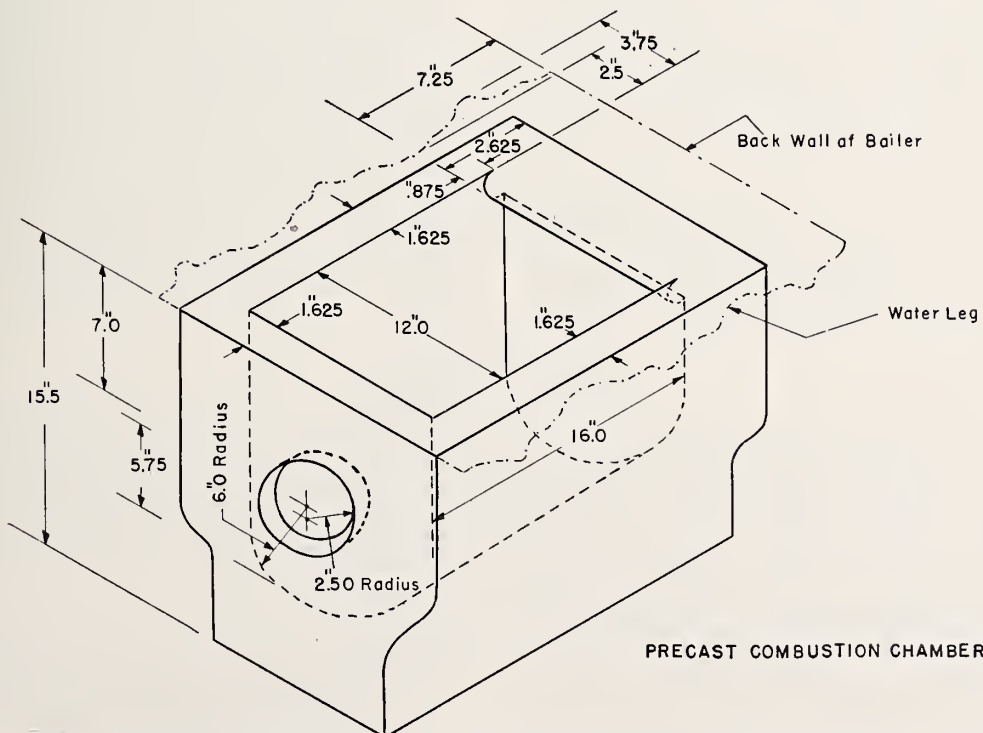
The volume of the firebrick combustion chamber was 1.26 cu ft and of the precast chamber 1.30 cu ft, exclusive of the space from the top of the chamber to the crown sheet of the boiler, which

¹ Figures in brackets indicate the literature references at end of this paper.



FIREBRICK COMBUSTION CHAMBER

FIGURE 1. Firebrick combustion chamber made of standard $2\frac{1}{2}$ - by $4\frac{1}{2}$ - by $9\frac{1}{2}$ -in. firebrick.



PRECAST COMBUSTION CHAMBER

FIGURE 2. Precast combustion chamber consisting of eight pieces of refractory fitted together.

was the same in both cases. The two chambers were located similarly with respect to the water legs and to the front and back sections of the boiler. Therefore, the differences in size and location of the two chambers were negligible.

The crown-sheet baffle was a cast-iron plate, $\frac{1}{2}$ in. thick, bolted to the back of the boiler through one of the holes normally used for the domestic hot-water heating coil. This plate extended forward in a horizontal plane for a distance of 12 in. from the back of the boiler. It was as wide as the interior width of the boiler reaching from the back of the boiler to the joint between the second and third sections. The plane of the baffle was 6 in. below the crown sheet and 12 in. above the top of the combustion chamber. A diagrammatic cross section of a cast-iron boiler illustrating the application of the crown-sheet baffle is shown in figure 3.

The baffles used in the uptake flues were $2\frac{1}{4}$ - by 6-in. cast-iron plates. They were placed in the two forward uptakes in the third section entirely closing the openings. The position of these baffles is also illustrated in figure 3.

The steam risers from the boiler were brought up full size to a level of 30 in. above the top of the boiler and were connected together into a header. Pipe connected the header to a steam separator, a gate valve, and a surface condenser. The piping was insulated with 2-in. magnesia pipe covering. The condensate was weighed on a platform scale graduated in quarter ounces. The drafts in the firebox and in the smoke pipe were measured with draft gages graduated in thousandths of an inch W. G. (water gage). Feed water was introduced into one of the water legs of the boiler was maintained at a constant height by a constant-level valve in the feed line.

The smoke pipe was connected to the vertical outlet of the smokehood and was attached to an induced-draft fan. The smokehood and 2 ft of the smoke pipe were insulated with 2 in. of rock wool. An orifice plate inserted in the insulated portion of the stack served to mix the

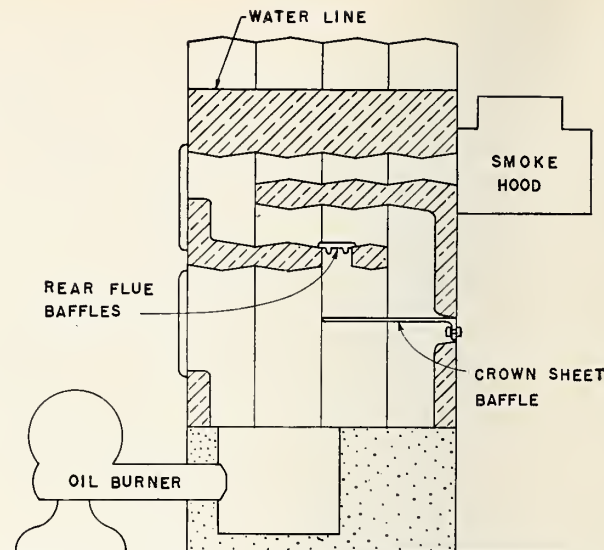


FIGURE 3. Diagram of a cast-iron boiler showing position of baffles.

Not drawn to scale.

flue gases and give a more nearly uniform temperature across the area of the smoke pipe. The flue-gas temperature was measured at the center of this orifice with a chromel-alumel thermocouple of 26-gage wire. The stack draft was measured 3 in. below this orifice plate and a tube was inserted 3 in. above the plate for sampling the flue gases. The temperatures of the feed water and the steam were measured with copper-constantan thermocouples of 30-gage wire. Steam was taken from the boiler at atmospheric pressure. The oil-supply tank rested on a platform scale graduated in quarter ounces. A siphon was used to connect the oil supply to the oil burner to allow free movement of the scale platform. A watt-hour meter graduated in divisions of 10 watt-hours integrated the energy used by the burner motor and the ignition circuit. An Orsat apparatus was used to measure the carbon dioxide content of the flue gases.

III. Procedure

In order to permit ready comparison of the capacity and efficiency of the converted boiler with the different combustion chambers and baffles, a fixed set of conditions was substantially reproduced during the first test after each modification of the boiler. The "fixed" conditions were established during a preliminary heating period by adjusting the rate of fuel supply, the draft, and the air openings into the burner to produce a stack temperature of approximately 600° F, a concentration of 10 percent of carbon dioxide in the flue gas, and a draft of 0.02 in. W. G. in the firebox. The heat imparted to the water under

these specified conditions is called the "gross rated output" or, more briefly, the "capacity" of the boiler, measured in Btu per hour.

The output of the boiler under each of the test conditions was computed by means of the following formula:

$$\text{Output} = W(h_{fg} + h_f - h_i),$$

in which

h_{fg} = heat of vaporization of water at the measured steam temperature, Btu/lb.

h_f = heat of the liquid of water at the steam temperature, Btu/lb.

h_f = heat of the liquid of water at the feed water temperature, Btu/lb.

W = water rate, lb/hr determined by weighing the condensate.

By definition, the heat input to the boiler is the product of the weight of oil burned per hour and the heating value of the oil. The direct efficiency is the ratio of the output, determined by water rate and enthalpy change, to the input. The input which results in producing the gross rated output of heat will be called normal.

When the normal input had been determined, three sets of observations were made with fuel inputs of approximately 80, 100, and 120 percent of normal, but with the same firebox draft and with flue gases of the same composition.

During a warming-up period of at least 90 minutes before each test, the soot was brushed off the heating surfaces, the firebox draft was adjusted, the oil input was regulated, and the air opening on the burner was opened or closed to produce the desired operating conditions. At the time of starting the test, the oil scale was balanced, the watt-hour meter was read, and a container was placed under the condensate outlet. Thereafter, the following observations were made at 15-minute intervals during a 2-hr test period: Oil consumption; steam condensed; electric energy

used; draft in the firebox and stack; temperatures of the feed-water, steam, and flue gas; gage-glass level; room temperature; barometer; oil pressure on the nozzle; and carbon dioxide and oxygen content of the flue gases. The rate of oil consumption was adjusted by varying the pressure on the nozzle within reasonable limits. When greater variation of input was necessary, a different sized nozzle was inserted in the burner.

The manufacturer of the oil burner recommended a No. 3 fuel oil for use in the boiler under test. Two No. 3 fuel oils with specific gravities of 0.863 and 0.871 and total heating values of 19,400 and 19,300 Btu/lb., respectively, were used.

Tests at 80, 100, and 120 percent of gross rated output were made with the firebrick combustion chamber without baffles. For the next series of experiments, this chamber was replaced by the precast chamber. Subsequently, the crown-sheet baffle was used alone with the precast chamber, and later both the crown-sheet and rear-flue baffles were used with the same chamber for a similar series of tests. An additional set of three tests was made under the last operating condition, with fire door, clean-out door, and clinker door sealed against leakage of air. In all the previous tests no attempt was made to reduce the air leakage around the doors.

IV. Test Results on Combustion Chambers

The results of the tests of the boiler equipped with the precast combustion chamber and with the firebrick combustion chamber without baffles, are plotted in figure 4. It will be noted in this figure that the gross rated output of the boiler, at a stack temperature of 600° F and 10 percent

of carbon dioxide in the flue gases, was 115,000 Btu/hr with the precast chamber and 112,000 Btu/hr with the firebrick chamber; whereas the efficiency of the boiler was nearly 5 percent greater with the precast chamber. The data from which figure 4 is plotted are summarized in table 1.

TABLE 1. Performance of a converted coal-fired boiler^a equipped successively with firebrick combustion chamber and precast combustion chamber

	Test number and type of combustion chamber						
	1. Firebrick	2. Firebrick	3. Firebrick	4. Firebrick	5. Precast	6. Precast	7. Precast
Grade of oil.....	No. 3	3	3	3	3	3	3
Burner nozzle size.....	gal/br. 1.35	1.35	1.35	1.35	1.65	1.65	1.65
Oil input rate.....	lb/br. 6.93	8.96	9.00	10.21	8.22	9.12	10.77
Heating value of oil.....	Btu/lb. 19,400	19,400	19,400	19,400	19,400	19,400	19,400
Heat input rate.....	Btu/br. 134,400	173,900	174,600	198,120	159,400	176,900	208,900
Steam condensed.....	lb/br. 79.50	100.25	102.25	116.12	99.04	109.86	125.73
Heat to produce steam.....	($h_{fg} + h_f - h_i$), Btu/lb. 1,102.2	1,102.3	1,099.6	1,101.5	1,112.8	1,110.2	1,113.2
Gross output.....	Btu/br. 87,630	110,510	112,430	127,910	110,210	121,970	139,960
Direct efficiency.....	percent 65.1	63.5	64.3	64.5	69.1	68.9	66.9
Draft, firebox.....	in. W. G. 0.022	0.020	0.021	0.021	0.019	0.021	0.020
Draft, stack.....	in. W. G. .017	.017	.020	.020	.010	.011	.015
Flue-gas temperature.....	°F 524	605	603	643	590	607	662
CO ₂ in flue gas.....	percent 10.1	10.0	9.7	10.0	10.0	10.1	10.0
Wet flue-gas loss.....	percent 19.5	22.3	22.5	23.2	21.7	22.3	23.7
Radiation and incomplete combustion loss.....	percent 15.4	14.2	13.2	12.3	9.2	8.8	9.4
Radiation and incomplete combustion loss.....	Btu/hr. 20,720	24,670	23,000	24,380	14,670	15,550	19,630
Burner power consumption.....	watts 135	179	175	198	190	202	207

^a No baffles were used in the boiler for these tests.

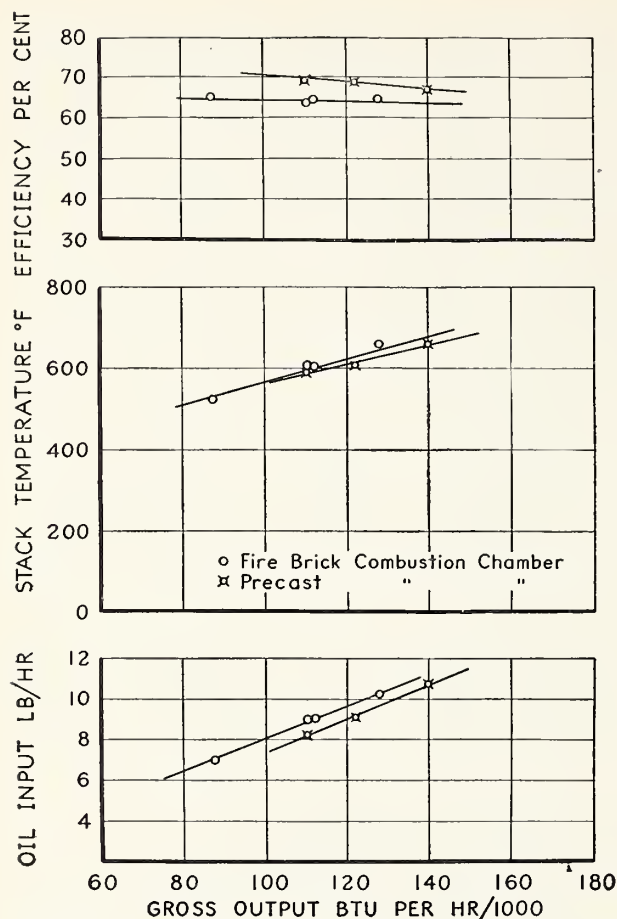


FIGURE 4. Comparison of the performance of a boiler equipped with firebrick combustion chamber with that of the same boiler equipped with precast combustion chamber.

No baffles were used in either case.

For a gross output of 115,000 Btu/hr, figure 4 shows that the boiler efficiency was about 64.2 percent with the firebrick combustion chamber and 69.0 percent with the precast combustion chamber. The oil consumption rate was 9.26 lb/hr in the former case and 8.67 lb/hr in the latter, representing a fuel saving of 6.3 percent when the precast chamber was used.

The heat available from the fuel oil consumed during these tests may be divided into three parts for the purpose of this discussion. The major or first part appeared as useful heat in the steam being delivered from the boiler. The second part passed up the chimney in the flue gases; this included the heat carried away by the water vapor produced by the combustion of hydrogen in the fuel. The third part was either dissipated from the boiler setting by radiation, conduction, and convection (hereafter referred to simply as the radiation loss), or was represented by fuel that passed up the chimney without burning. With

10 percent of carbon dioxide in the flue gas and a stack temperature of 600° F, the second item of the three above-mentioned is about 22.3 percent of the heating value of the fuel. Thus, the sum of the first two items when the firebrick combustion chamber was used was 85.8 percent in test 2 and 91.2 percent when the precast chamber was used in test 6, summarized in table 1. Hence, the radiation and incomplete combustion loss in the first case was 14.2 percent and in the second case 8.8 percent of the heat available in the fuel.

The precast chamber became visibly hotter than the firebrick combustion chamber during continuous operation. The former reached a medium cherry red color over its entire inside surface, whereas the latter did not glow visibly at any place during the course of the tests. This indicates that the flow of heat from the area of combustion through the refractory of the chamber was less for the precast material than for the firebrick. Evidently, the higher temperature of the precast chamber considerably increased the radiation of heat to the boiler, since more heat was liberated in the combustion chamber in test 6 than in test 2, whereas, the flue-gas temperatures were practically identical during the two tests.

In this paper the terms "precast" and "firebrick" are used to identify the two combustion chambers. It should be pointed out that the better results obtained with the precast chamber depended on the properties of the material used to construct the combustion chamber, and in particular on its thermal conductivity, heat capacity, and shape, rather than on the fact that it was of precast construction.

Figure 4 shows the performance of the boiler with each combustion chamber for a range of output from about 20 percent below to 20 percent above the gross rated output defined under Procedure, chapter III, of this report. Over this range, with the brick combustion chamber, the efficiency remained within narrow limits, between 63.5 and 65 percent. Presumably, changes in radiation and incomplete combustion losses, due to altering the output, were approximately compensated for by opposite changes in flue-gas losses. Over the same range of output, the efficiency with the precast chamber varied from about 71 percent at 88,000 Btu/hr output, obtained by extrapolation, to about 67 percent at 132,000 Btu/hr output, taken from figure 4.

The data in table 1 show that, in general, the heat lost by radiation and incomplete combustion expressed in Btu per hour increased as the rate of fuel consumption increased. The sum of these two losses was some 8,000 to 9,000 Btu/hr greater with the firebrick combustion chamber than with the precast combustion chamber at the same gross output.

V. Boiler Performance with Baffles

A comparison of the results obtained with and without the use of baffles shows that the use of the crown-sheet baffle alone increased the gross rated output of the boiler about 12 percent, but that it had no effect on the efficiency. The use of both the crown-sheet and the rear-flue baffles increased the gross rated output about 27 percent and increased the efficiency 1 or 2 percent. All of these tests were made with the precast combustion chamber installed in the boiler. At a stack temperature of 600° F and with 10 percent carbon dioxide in the flue gas, the gross rated output of the boiler without either baffle was 115,000

Btu/hr and the efficiency was 69.1 percent. With only the crown-sheet baffle in use, the gross rated output was 128,500 Btu/hr and the efficiency was 68.8 percent; with both baffles installed, the gross rated output was 146,000 Btu/hr and the efficiency was 70.8 percent. The results of the tests made with the crown-sheet baffle are summarized in table 2, while those obtained with both baffles are contained in table 3. The results in tables 2 and 3 and tests 5 to 7 in table 1 are plotted in figure 5 to compare the performance of the boiler with and without baffles.

TABLE 2. Performance of a converted coal-fired boiler equipped with a crown-sheet baffle

		Test number and type of combustion chamber			
		1. Precast	2. Precast	3. Precast	4. Precast
Grade of oil.....	No.	3	3	3	3
Burner nozzle size.....	gal/hr	1.65	1.65	1.65	1.65
Oil input rate.....	lb/hr	8.15	8.23	10.27	11.51
Heating value of oil.....	Btu/lb	19,400	19,400	19,400	19,400
Heat input rate.....	Btu/hr	158,000	159,600	199,200	223,500
Steam condensed.....	lb/hr	98.00	97.98	125.50	139.25
Heat to produce steam.....	($h_{fg} + h_f - h_i$), Btu/lb	1,106.2	1,110.7	1,105.9	1,105.1
Gross output.....	Btu/hr	108,410	108,830	138,790	153,890
Direct efficiency.....	percent	68.6	68.1	69.6	68.8
Draft, firebox.....	in. W. G.	0.020	0.021	0.020	0.020
Draft, stack.....	in. W. G.	.012	.011	.019	.025
Flue-gas temperature.....	°F	557	571	603	641
CO ₂ in flue gas.....	percent	10.1	9.9	10.2	10.0
Wet flue-gas loss.....	percent	21.0	21.3	22.3	23.3
Radiation and incomplete combustion loss.....	percent	10.4	10.6	8.1	7.9
Radiation and incomplete combustion loss.....	Btu/hr	16,420	16,910	16,120	17,640
Burner power consumption.....	watts	195	193	208	226

TABLE 3. Performance of a converted coal-fired boiler equipped with crown-sheet baffle and rear-flue baffles

		Test number and type of combustion chamber							
		1. Precast	2. Precast	3. Precast	4. Precast	5. Precast	6. Precast	7. Precast	8. Precast
Grade of oil.....	No.	3	3	3	3	3	3	3	3
Burner nozzle size.....	gal/hr	1.00	1.35	1.35	1.65	2.00	1.65	1.65	2.09
Oil input rate.....	lb/hr	5.55	7.09	8.31	10.60	10.92	11.03	12.69	15.41
Heating value of oil.....	Btu/lb	19,300	19,300	19,300	19,300	19,300	19,300	19,300	19,300
Heat input rate.....	Btu/hr	107,120	136,910	160,440	204,600	210,780	212,900	244,860	297,335
Steam condensed.....	lb/hr	67.87	87.05	102.41	129.71	132.29	131.81	149.27	183.01
Heat to produce steam.....	($h_{fg} + h_f - h_i$), Btu/lb	1,107.2	1,117.1	1,117.5	1,116.4	1,118.8	1,119.1	1,120.6	1,103.2
Gross output.....	Btu/hr	75,150	97,240	114,400	144,810	148,110	147,510	167,270	202,500
Direct efficiency.....	percent	70.1	71.0	71.2	70.6	70.1	69.2	68.3	68.1
Draft, firebox.....	in. W. G.	0.020	0.021	0.021	0.021	0.022	0.021	0.020	0.030
Draft, stack.....	in. W. G.	.008	.023	.010	.021	.022	.021	.026	.051
Flue-gas temperature.....	°F	408	495	525	599	603	606	644	703
CO ₂ in flue gas.....	percent	9.9	9.8	10.0	9.8	9.9	10.0	9.9	9.9
Wet flue-gas loss.....	percent	16.7	19.0	19.8	22.5	22.5	22.4	23.5	25.7
Radiation and incomplete combustion loss.....	percent	13.2	10.0	9.0	6.9	7.4	8.4	8.2	6.2
Radiation and incomplete combustion loss.....	Btu/hr	14,150	13,690	14,440	14,110	15,600	17,890	20,040	18,420
Burner power consumption.....	watts	141	146	143	135	208	217	231	163

Figure 5 shows the oil input, stack temperature, and efficiency of the boiler for a range of gross output from about 90,000 to 170,000 Btu/hr: when using the crown-sheet baffle only, when using both baffles, and when using no baffle, all with the precast combustion chamber. The curves indicate that, at some typical intermediate gross output such as 130,000 Btu/hr, the use of both baffles

reduced the stack temperature from 635° to 565° F, reduced the fuel consumption from 10.0 to 9.5 lb/hr, and increased the efficiency from 68.2 to 70.5 percent; for this gross output, the baffles effected a fuel saving of 5 percent.

Figure 6 affords a comparison of the performance of the boiler equipped with the precast combustion chamber and both baffles with that of the

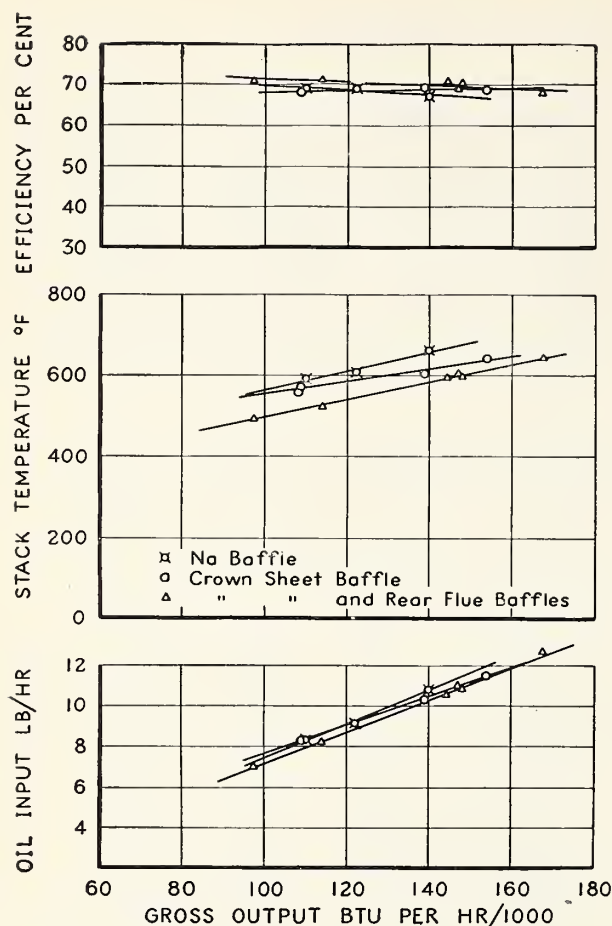


FIGURE 5. Effect of using the crown-sheet baffle alone and in conjunction with the rear-flue baffles in a boiler equipped with precast combustion chamber.

same boiler equipped with the firebrick combustion chamber with no baffles. The gross rated output was increased from 112,000 to 146,000 Btu/hr or 30.3 percent by installation of the baffles and the precast combustion chamber. Again comparing the performance at 130,000 Btu/hr gross output, the curves show that the precast chamber and baffles reduced the stack temperature from 655° to 565° F, reduced the oil consumption rate 9.5 percent from 10.5 to 9.5 lb/hr, and increased the efficiency from 64.1 to 70.5 percent.

All of the tests previously discussed were conducted without sealing the fire door, the clinker door, and the clean-out door against leakage of air into the combustion chamber. Inasmuch as these doors are frequently sealed in oil-burning installations, tests were made to determine what effect this leakage had on the performance of the boiler. Figure 7 shows the characteristics of the boiler for a range from approximately 80 to 120 percent of gross rated output with the doors sealed when

the precast firebox and both baffles were used. The indications are that sealing the doors did not alter the efficiency for the gross output of 120,000 Btu/hr and increased it only one percent for a gross output of 170,000 Btu/hr. Sealing the doors appreciably increased the gross rated output from 146,000 to 152,000 Btu/hr and the oil consumption was increased 0.42 lb/hr. Under the method of control used for the tests, sealing the doors would be expected to increase the primary air by an amount equal to the leakage at the doors which should increase the completeness of combustion. It should also prevent interference with the heat transfer by an envelope of relatively cool air leaking in around the hot combustion gases. Therefore, an increase in efficiency and heat transfer would be expected from sealing the doors. Figure 7 was plotted from the results of tests 1 to 3, inclusive, shown in table 4.

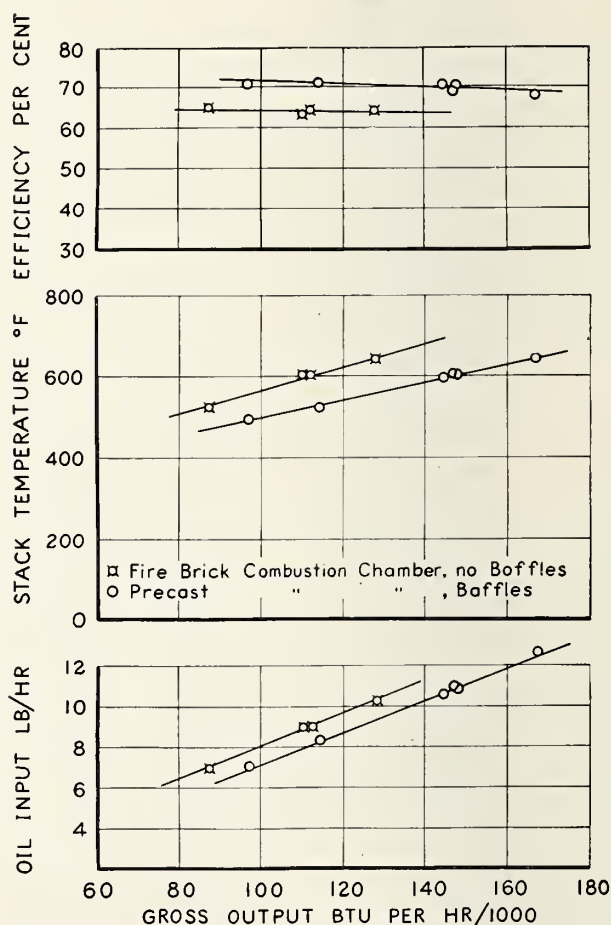


FIGURE 6. Comparison of the performance of a boiler equipped with firebrick combustion chamber and no baffles with that of the same boiler equipped with precast combustion chamber, crown-sheet, and rear-flue baffle.

TABLE 4. Performance of a converted coal-fired boiler^a with fire door and cleanout door sealed

		Test number and type of combustion chamber		
		1. Precast	2. Precast	3. Precast
Grade of oil.....	No.	3	3	3
Burner nozzle size.....	gal/hr.	1.35	1.65	1.65
Oil input rate.....	lb/hr.	9.00	11.14	12.85
Heating value of oil.....	Btu/lb.	19,300	19,300	19,300
Heat input rate.....	Btu/hr.	173,700	215,020	248,030
Steam condensed.....	lb/hr.	111.27	139.30	155.72
Heat to produce steam.....	$(h_{fg} + h_f - h_i)$, Btu/lb.	1,098.6	1,098.3	1,099.6
Gross output.....	Btu/hr.	122,240	153,000	171,230
Direct efficiency.....	percent	70.3	71.1	69.0
Draft, firebox.....	in. W. G.	0.021	0.020	0.019
Draft, stack.....	in. W. G.	.010	.019	.023
Flue-gas temperature.....	°F	538	598	646
CO ₂ in flue gas.....	percent	10.0	10.1	10.0
Wet flue-gas loss.....	percent	20.5	22.3	23.4
Radiation and incomplete combustion loss.....	percent	9.2	6.6	7.6
Radiation and incomplete combustion loss.....	Btu/hr.	15,980	14,200	18,830
Burner power consumption.....	watts	145	140	151

^a Both crown-sheet and rear-flue baffles were used for these tests.

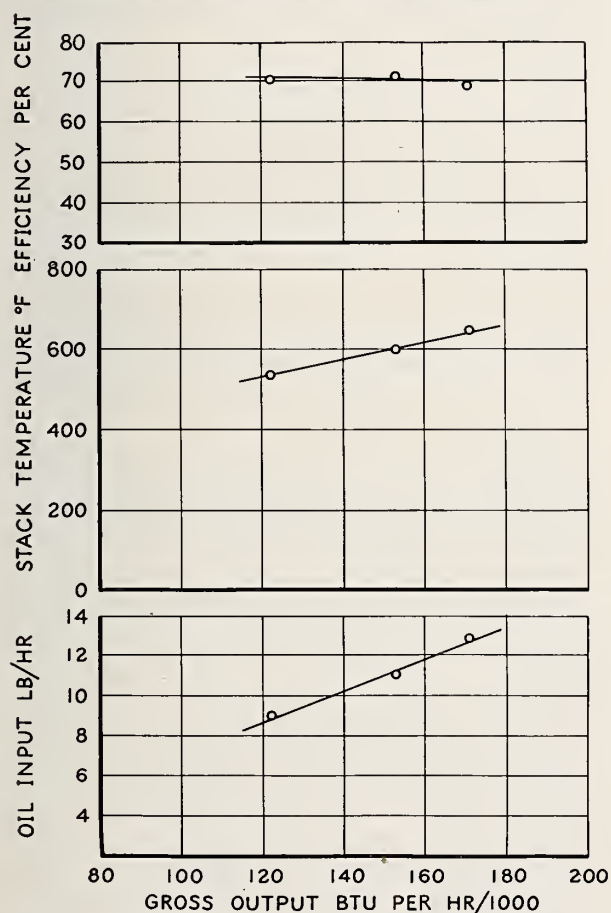


FIGURE 7. Performance of a boiler equipped with precast combustion chamber, crown-sheet, and rear-flue baffles when the fire door, clinker door, and clean-out door are sealed.

Figure 8 shows the performance of the converted boiler using the precast combustion chamber with both baffles for a range of gross output from 75,000 to 200,000 Btu/hr. The maximum efficiency of

the combination boiler-burner unit occurred at a gross output of about 120,000 Btu/hr. However, the efficiency remained above 68 percent for the

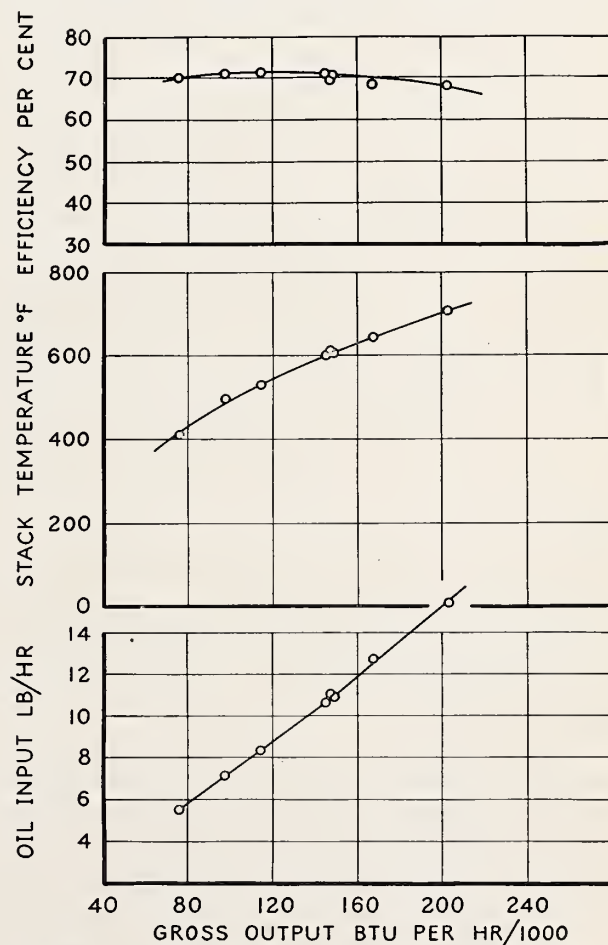


FIGURE 8. Performance of a boiler for heat output ranging from 75,000 to 200,000 Btu/hr.

Boiler equipped with precast combustion chamber, crown-sheet, and rear-flue baffle.

entire range of output shown. The lowest oil input of 5.6 lb/hr was obtained with a 1.00-gal/hr nozzle under a pressure of 105 lb/in.² and the highest oil input of 15.5 lb/hr was obtained with a 2.00-gal/hr nozzle under a pressure of 145 lb/in.². Some soot was deposited on the heating surfaces

at the lower firing rates when the 1.00-gal/hr and 1.35-gal/hr nozzles were used, but at the higher firing rates no soot was visible on the heating surfaces at the end of the test. Figure 8 was plotted from the results of tests 1 to 8, inclusive, shown in table 3.

VI. Discussion and Conclusions

The results of this work are considered to establish the general possibility of improving the efficiency and of increasing the ratings or capacities of boilers after conversion from the use of coal to oil, by means of baffles in the flue passages and combustion chamber, by means of precast combustion chambers of special shape and low-density material, and by sealing the fire door to prevent leakage.

The results of the particular tests reported herein show that an improvement in efficiency of 5 percent and an increase in capacity of 2½ percent are possible by the use of a typical precast combustion chamber in a typical cast-iron coal-fired heating boiler. Boiler capacity or rating has been defined as the heat output when the firing rate is regulated to maintain the stack temperature at 600° F, a concentration of 10 percent of carbon dioxide in the flue gas, and a draft of 0.02 in. W. G. in the firebox. On this basis, the results also show that boiler rating or capacity can be raised 27 percent and the efficiency about 2 percent by the use of a crown-sheet baffle and rear-flue baffles. These results are attributed to higher temperatures in the combustion chamber, to the greater turbulence of the flue gases, and to more effective circulation of the combustion gases over the heat-transfer surfaces, all caused by the baffles.

Sealing the fire doors against air leakage increased the boiler capacity or rating about 4 percent but did not measurably improve the efficiency.

Boilers differ in their proportions; therefore, the same design of baffle or of combustion chamber is not applicable to every boiler. To convert a given boiler from coal- to oil-firing, the user should apply to the boiler manufacturer or to some other competent source for information and for the necessary parts.

In addition to the use of baffles, boiler capacity can also be increased and the efficiency improved slightly by adding sections to a cast-iron boiler, thereby increasing the heating surface. The problem may arise as to whether it is more economical to attain an increase in boiler capacity by the use of baffles, by the installation of additional sections in a cast-iron boiler, or by the use of a new and larger boiler. It is anticipated that, of the three methods of increasing boiler capacity, the use of

baffles will prove to be the best expedient, as no change in piping or other arrangements would be entailed.

A summary of the results obtained on the converted boiler, by using two different combustion chambers and one or two sets of baffles, with the fuel-air mixture set to produce 10 percent carbon dioxide in the flue gas, a stack temperature of 600° F, and 0.02-in. W. G. draft in the firebox, is shown in table 5.

TABLE 5. Summary of boiler performance for five test conditions

[Carbon dioxide 10 percent, stack temperature 600° F, firebox draft 0.02-in. W. G.]

Combustion chamber	Baffles	Gross rated output	Efficiency	Oil input
		Btu/hr	Percent	Lb/hr
Firebrick.....	None.....	112,000	64.3	9.05
Precast.....	do.....	115,000	69.1	8.72
Do.....	Crown-sheet.....	128,500	68.8	9.70
Do.....	Crown-sheet and rear-flue.....	146,000	69.5	10.78
Do.....	do.....	* 152,000	70.4	11.20

* Fire door, clean-out door, and clinker door sealed.

Although all of the tests reported were made with the oil burner operating continuously, it is expected that the type of combustion chamber and baffles used would have similar effects on the efficiency and capacity of the boiler with intermittent operation. Investigations by L. E. Seeley and E. J. Tavanlar [4] have shown that oil-burning boilers are less efficient when operating intermittently than when operating continuously, especially when the ratio of operating time to idle time is small. A lightweight combustion chamber, such as the precast specimen, should provide a greater improvement in efficiency for intermittent operation than for steady operation because it becomes hot more rapidly. Also, the present tests were made with a flue-gas carbon dioxide content of 10 percent to correspond with the requirement of the applicable commercial standard, CS75-42 [5]. The probability is that the lightweight combustion chamber would show a still greater advantage if smoke production rather than carbon dioxide in the flue gas were made a limitation, since the higher surface temperature of a lightweight combustion chamber should favor better combustion.

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